



**Europäisches  
Patentamt**

**European  
Patent Office**

**Office européen  
des brevets**

PCT / IB 0 3 / 0 3 9 '9 2

0 1. 09. 03

REC'D 30 SEP 2003

WIBS PCT

**Bescheinigung**

**Certificate**

**Attestation**

**BEST AVAILABLE COPY**

Die angehefteten Unterla-  
gen stimmen mit der  
ursprünglich eingereichten  
Fassung der auf dem näch-  
sten Blatt bezeichneten  
europäischen Patentanmel-  
dung überein.

The attached documents  
are exact copies of the  
European patent application  
described on the following  
page, as originally filed.

Les documents fixés à  
cette attestation sont  
conformes à la version  
initialement déposée de  
la demande de brevet  
européen spécifiée à la  
page suivante.

**Patentanmeldung Nr. Patent application No. Demande de brevet n°**

02078749.5

**PRIORITY DOCUMENT**  
SUBMITTED OR TRANSMITTED IN  
COMPLIANCE WITH  
RULE 17.1(a) OR (b)

Der Präsident des Europäischen Patentamts;  
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets  
p.o.

**R C van Dijk**



Europäisches  
Patentamt

European  
Patent Office

Office européen  
des brevets

Anmeldung Nr:  
Application no.: 02078749.5  
Demande no:

Anmeldetag:  
Date of filing: 10.09.02  
Date de dépôt:

Anmelder/Applicant(s)/Demandeur(s):

Koninklijke Philips Electronics N.V.  
Groenewoudseweg 1  
5621 BA Eindhoven  
PAYS-BAS

Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:  
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.  
If no title is shown please refer to the description.  
Si aucun titre n'est indiqué se référer à la description.)

Transmission power optimization in OFDM wireless communication system

In Anspruch genommene Priorität(en) / Priority(ies) claimed /Priorité(s)  
revendiquée(s)

Staat/Tag/Aktenzeichen/State/Date/File no./Pays/Date/Numéro de dépôt:

Internationale Patentklassifikation/International Patent Classification/  
Classification internationale des brevets:

H04L5/00

Am Anmeldetag benannte Vertragsstaaten/Contracting states designated at date of  
filing/Etats contractants désignées lors du dépôt:

AT BE BG CH CY CZ DE DK EE ES FI FR GB GR IE IT LI LU MC NL PT SE SK TR

13. 09. 2002

(93)

The invention refers to an OFDM Wireless Communication Method and System.

All recent wireless technology developments, although pulled by different market requirements and applications (e.g., WLAN's for portable connectivity in office IT enterprises, WPAN's for cable replacement and personal sphere interconnectivity, etc.), have been characterized by a common quest for higher capacity density and link speed, on one hand, and greater reliability and flexibility in the presence of varying channel conditions and/or traffic loading and QoS system requirements, on the other.

To this purpose, an architecture is necessary that realizes a joint adaptive strategy across lower layers, aiming at the dynamic optimization of system performance in scenarios entailing time-varying service requirements and channel conditions. To sustain such features, all basic radio interface schemes (i.e. modulation, coding, access scheme, etc.) have to be designed so as to allow highly granular flexible variations of their parameters, instantiated by adaptive algorithms and reconfigurable sub-systems. Moreover, in order to affect adaptivity at the physical layer, a possible solution is to keep the slot (symbol) and frame length fixed, and to vary the triplet of modulation size, code rate, and transmitted power.

A transceiver architecture of the above kind is shown in Figure 1. The transceiver comprises, on the transmitter side, a MAC layer 2 which is connected to a supervisor 4 and a turbo encoder 6. The supervisor is connected to the turbo encoder 6 and an OFDM modulator 8 which also receives an output from the turbo encoder 6. The output of the OFDM modulator is fed through high power amplifier 10 to an antenna 12.

At the receiver side, an antenna 14 receives the signal and feeds it to a low noise amplifier 16. The output of the low noise amplifier 16 via a channel estimator 18, an OFDM demodulator 20 and a turbo decoder 22 to a MAC layer 24 on the receiver side.

In such an arrangement, a supervisor 4 is needed. The supervisor is the basic processing and control unit of any adaptive and re-configurable system meant to perform, at run-time, a pre-defined system optimization. The inputs and outputs of the supervisor are both parameters and directives. The task of supervisor is to solve the problem of fitting the

QoS (Quality of Service) requirements from the MAC (Medium Access Control) layer, given the current channel conditions (input parameters), with the minimum transmitted power. The output parameters could be the different coding and modulation scheme, the adjusted transmitted power and the subset of the sub-carriers to be excised. The channel (except noise)

5 is considered reciprocal. So the TX (Transmitter) can adjust the transmitter parameters

according to measurements done at the RX (Receiver). The values of transmitter parameters currently in use are then communicated to the RX of the other side of the link, and demodulated enabling the actual data demodulation.

At the MAC layer the bit transmission is organized in a Time Division  
10 Multiple Access (TDMA) way. The time axis could be divided into frames which, in turn, could be divided into time slots, characterized by a fixed time duration which entails a fixed frame duration and a variable number of bits carried out, number, depending on the adopted coding/modulation scheme.

It is an object of the invention to provide a method and a system to manage the  
15 system flexibility while minimizing processing and/or transmission power in a flexible and reciprocal OFDM wireless communication system.

To achieve this object, there is provided a method for minimizing transmission power in an OFDM wireless communication system including a MAC layer and a PHY layer, said PHY layer including a supervisor unit controlling performance of the PHY layer,  
20 wherein:

- a) processing of first and second sets of input data for minimizing transmission power in a wireless communication network system comprises:
- b) calculating the maximum bit rate achievable by every couple M/C, identified by modulation  $k$  and code-rate  $i$ , with all sub-channels turned on;
- 25 c) eliminating the couples M/C for which the maximum achievable bit rate is less than the requested one;
- d) for every couple useful M/C:
  - d1) calculate the minimum number of sub-channels required to achieve the bit rate  $B$ ;
  - 30 d2) derive, from simulation-based curves, the SNR necessary to obtain the required BER in the AWGN case and use it to derive the SNR required by the worst sub-channel;
- e) calculate the total received power for all  $N^{(k,i)}$  sub-channels;

f) select and output an "optimum" couple M/C  $((M,C)_{\min\_pow})$  which minimizes  $P_r^{(k,i)}$ :

$$P_{r,\min\_pow} = \min_{(k,i)} \{P_r^{(k,i)}\} .$$

According to a preferred embodiment of the method of the invention, in case the starting information is the maximum transmit power and the Target\_BER, the processing of the first and second set of input data for minimizing transmission power in a wireless communication network system comprises:

- a) calculate the maximum received power;
- b) calculate the minimum SNR on the weakest sub-channel, for every number  $j$  of sub-channels considered and store the result;
- c) for every couple M/C, calculate the number of sub-channels having an SNR above the threshold yielding the BER requested by the MAC sub-layer;
- d) calculate the bit rate achievable using  $N^{(k,i)}$  sub-channels;
- e) find the M/C (called  $(M,C)_{\max}$ ) yielding the maximum bit rate; and
- f) select and output an "optimum" couple M/C (called  $(M,C)_{\max}$ )

According to a preferred embodiment of the method of the invention, in case the starting information is the maximum transmit power and the Target\_Rate, the processing of the first and second set of input data for minimizing transmission power in a wireless communication network system comprises:

- a) calculate the maximum receive power;
- b) for every M/C, calculate the number of sub-channels used to achieve the bit rate Target\_Rate;
- c) select the SNR on the worst sub-channel;
- d) calculated from the BER-SNR curve the BER corresponding to the worst sub-channel for modulation  $k$  and code-rate  $i$ ;
- e) find the M/C (called  $(M,C)_{\min}$ ) yielding the minimum value; and
- f) select and output an "optimum" couple M/C (called  $(M,C)_{\min}$ ).

To achieve the above object, there is provided a method for minimizing processing power in an OFDM wireless communication system including a MAC layer and a PHY layer, said PHY layer including a supervisor unit controlling performance of the PHY layer, wherein:

- a) processing of first and second sets of input data comprises:

- b) comparing Target\_Rate and  $\text{Rate}_\text{(N)} = C_\text{*} \log(M_\text{*}) * N$  for each available N (from 1 to max\_available\_N);
- c) selecting and accepting the values of N satisfying  $\text{Target\_Rate} \leq \text{Rate}_\text{(N)}$ ;
- d) ordering these values in ascending order to get  $[N_\text{min}, N_\text{max}]$
- 5 e) assuming  $N_\text{opt} = N_\text{min}$ ; and
- f) provide  $N_\text{opt}$  and minimum TX power parameters as output.

According to a preferred embodiment, the method of the invention further comprises, after assuming  $N_\text{opt} = N_\text{min}$ ,

- checking if the transmission power constraint is satisfied, if so provide  $N_\text{opt}$
- 10 and minimum TX power parameters as output, if not
- go on to check if another value is available in the set  $[N_\text{min}, N_\text{max}]$ , if so choose the next (next\_N), set N to next\_N and jump to selecting and accepting the values of N satisfying  $\text{Target\_Rate} \leq \text{Rate}_\text{(N)}$ , if not

set  $N_\text{opt} = 0$  and provide  $N_\text{opt}$  and minimum TX power parameters as output.

- 15 According to a preferred embodiment of the method of the invention, the processing of the first and second set of input data for minimizing transmission power in a wireless communication network system comprises:

selecting the best window position among the possible ones:

(max\_available N - ( $N_\text{opt} - 1$ )); and

- 20 running the adopted TX power minimization algorithm on the selected window.

According to a preferred embodiment, the method of the invention comprises feeding a first set of input data as to the QoS requirements at the PHY layer from the MAC layer to the supervisor unit; feeding a second set of input data including channel power transfer functions  $H = \{|H_i|^2\}$ : (index i refers to the  $i^{\text{th}}$  sub-carrier ) from PHY layer to the supervisor unit; processing the first and second set of input data for minimizing processing and transmission power in a wireless communication system; outputting N, modulation, coding parameters and transmission power parameters to the PHY layer;

- 30 According to a preferred embodiment of the method of the invention, the feeding of the first set of input data as to the QoS requirements at the PHY layer from the MAC layer to the supervisor unit comprises feeding a Target\_Rate (required information rate), a Target\_BER (required Bit Error Rate) and, preferably, a Max\_Delay (max tolerable delay).

According to a preferred embodiment of the method of the invention, the outputting of coding parameters and transmission power parameters to the PHY layer comprises:

N: IFFT/FFT length;

5 C: Code rate data;

B: Block length data;

n: data as to the number of decoding iterations;

M = {M<sub>i</sub>}: data as to a set of codes to specify the generally different constellations adopted for the different sub-channels (e.g. M<sub>i</sub>=0 means that the i<sup>th</sup> sub-channel is OFF, different values specify constellation types in the pre-defined available set); and

10 P = {P<sub>i</sub>}: data as to a set of the generally different transmission powers adopted for the different sub-channels (e.g. P<sub>i</sub>=0 means that the i<sup>th</sup> sub-channel is OFF).

According to a preferred embodiment, the method of the invention comprises outputting actual QoS data to the MAC layer.

15 According to a preferred embodiment of the method of the invention, outputting actual QoS data to the MAC layer comprises outputting an Actual\_Rate (rate actually determined for the current transmission); and an Actual\_BER (BER actually determined for the current transmission).

20 According to a preferred embodiment of the method of the invention the MAC layer requests a feedback specifying a Feedback\_mode [0/1] (one bit information to specify if MAC is interested to have a feedback information on the "current" maximum available rate or the minimum available BER), and, furthermore, specifies a Service\_mode [0/1] (one bit information to specify if MAC QoS requirements refers to a Rate guaranteed service or to a BER guaranteed service).

25 According to a preferred embodiment of the method of the invention wherein the outputting actual QoS data to the MAC layer additionally comprises, depending on the Feedback\_mode request from MAC layer, outputting a MAC\_return comprising a Max\_available\_Rate (maximum available rate for the current channel condition as far as BER and tolerable delay requirements are respected) or a Min\_available\_BER (minimum

30 available BER for the current channel condition as far as rate and tolerable delay requirements are respected) is provided after the optimization processing.

According to a preferred embodiment of the method of the invention the processing of the first and second set of input data for minimizing processing and transmission power in a wireless communication network system comprises finding N, the

M/C couple and the ON sub-channels required to fit the Target\_Rate and the Target\_BER requirements with the minimum power, given the current channel condition.

According to a preferred embodiment of the method of the invention, in case the channel conditions prevent from achieving the required QoS even with the maximum  
5 available transmission power the supervisor algorithm, (depending on Service\_mode) finds

~~the M/C couple, the number and the position of the ON sub-channels required to get the~~  
Maximum Rate compatible with the Target\_BER requirement, given the current channel condition and the maximum power allowed by the system specifications, or the Minimum BER compatible with the Target\_Rate requirement, given the current channel condition and  
10 the maximum power allowed by the system specifications.

To achieve the above object, there is provided an OFDM wireless communication system including a MAC layer and a PHY layer, said PHY layer including a supervisor unit controlling performance of the PHY layer for minimizing processing and transmission power of the wireless communication system, wherein the supervisor unit is  
15 configured to perform any of the above methods.

To achieve the above object, there is provided a supervisor unit in an OFDM wireless communication network system including a MAC layer and a PHY layer, said supervisor unit being included in the PHY layer and controlling performance of the PHY layer for minimizing transmission power of the wireless communication system, the  
20 supervisor unit is configured to perform any of the above methods.

To achieve the above object, there is provided an interface unit in an OFDM wireless communication system including a MAC layer and a PHY layer, said PHY layer including a supervisor unit controlling performance of the PHY layer for minimizing transmission power of the wireless communication network system, said interface being  
25 located between the supervisor unit and the MAC layer, wherein said interface unit is configured to perform any of the above methods.

To achieve the above object, there is provided a computer readable medium containing a computer readable program for minimizing processing power in an OFDM wireless communication system including a MAC layer and a PHY layer, said PHY layer  
30 including a supervisor unit controlling performance of the PHY layer for minimizing processing and transmission power of the wireless communication system wherein the program when implemented in the supervisor and run in the supervisor unit causes the supervisor to perform any of the above methods.



The invention exploits the flexibility which is introduced in the system implementation in order to be able, at run-time, to reconfigure and adapt the system itself with the purpose to minimize the processing and transmission power required to fulfil the QoS, given the current channel condition.

5           The invention provides in an advantageous way a high-performance, flexible, QoS-aware method for minimizing transmission power in a flexible and reciprocal OFDM wireless communication network system and a flexible and reciprocal OFDM wireless communication network system wherein the transmission parameters are optimized with a reduced processing complexity in order to be able to reconfigure, at run-time, the system  
10   itself with the purpose to minimize the transmission and/or the processing power required to fulfil the QoS, given the current channel condition. In particular, the reduction of the inherent power consumption in the mobile terminals of such a system is advantageous.

15           These and various other advantages and features of novelty which characterize the present invention are pointed out with particularity in the claims annexed hereto and forming a part hereof. However, for a better understanding of the invention, its advantages, and the object obtained by its use, reference should be made to the drawings which form a further part hereof, and to the accompanying descriptive matter in which there are illustrated  
20   and described preferred embodiments of the present invention.

Figure 1 is a block diagram of a wireless communication system network.

25           Figure 2 is a schematic representation of an embodiment of a supervisor unit to be used in a system of Figure 1.

Figure 3 is a more detailed schematic representation of the supervisor unit of Figure 2.

Figures 4A, 4B and 4C are graphical representations of full rate and reduced rate OFDM systems and down-scaled (I)FFT processing, respectively.

30           Figures 5A and 5B are a flow chart of an algorithm for an embodiment of the method to minimize transmission power parameters.

Figure 6 is a flow chart of an algorithm for an embodiment of the method to minimize the processing power and just refers to the algorithm in Figures 5A and 5B for the transmission power minimization processing.

Figure 7 is a flow chart of a procedure required by the embodiment of the method to minimize transmission power parameters (see Figures 5A and 5B) to obtain the minimum available BER.

5 Figure 8 is a flow chart of a procedure required by the embodiment of the method to minimize transmission power parameters to obtain the maximum available rate.

---

Figure 9 is a flow chart of a procedure required by the embodiment of the method to minimize transmission power parameters to order the channel gains.

Figure 10A, 10B and 10C show performance results obtained by applying the method using the algorithm.

10

In Figure 2 is a schematic representation of an embodiment of a supervisor unit to be used in a system of Figure 1 as specified above. As shown in Figure 3 which is a more detailed schematic representation of the supervisor unit of Figure 2, the supervisor is a building block, at physical layer, required to perform a real-time system optimization. System optimization is a context aware processing based on flexibility aiming at the real-time minimization of a given cost function. A system is defined to be flexible if it is at least adaptive and/or re-configurable. The context could refer to the changing QoS requirements and channel conditions, while the cost function could be, for instance, the power (transmission and/or processing power). The supervisor inputs are a set of parameters from the physical and MAC layers. The supervisor outputs are both a set of parameters and directives to the physical and MAC layers. The target of the supervisor is to find the best output directives and parameters values to minimize the cost function given the current inputs.

25 The supervisor inputs are just parameters while its outputs can be both parameters and directives. The term directive refers to the indication of an action to be executed (e.g. the reconfiguration of some sub-blocks to fit the requirements of a selected algorithm).

30 The supervisor performs its optimization at PHY level and this allows a true real-time optimization. The supervisor supplies also the  $MAC_{out}$  information to the upper layer allowing MAC to perform its own optimization process.

**Supervisor Algorithm: processing power minimization**

Continuing advances in VLSI and ASIC technology for low power application can just help to reduce the impact of the power consumption on battery life and so they can offer just a partial solution. Some complementary countermeasures would be needed to get an effective result. So we tried to approach the same problem from the system level point of view.

To be more specific, let's consider an OFDM-based system; assume that the rate is the main QoS requirement and that the transmitter knows the current channel condition. In traditional OFDM systems such information would be exploited just in order to find the best way to distribute bit and power aiming, for instance, at the transmission power minimization. Should the required rate be the maximum allowed by the specs or any other one, even if much lower, nothing would change from the processing power point of view. A low rate (e.g.  $\text{full\_rate}/4$ ) would be accommodated using less "active" sub-carriers (e.g.  $N_{\text{on}}/4$ ), that is feeding the OFDM modulator (IFFT) with a certain number of zeros (see Figure 4B). Though useful to save transmission power, this doesn't have an impact on the processing power: the processing block, the FFT, will continue to work at full speed, being the potential total bandwidth the same.

Suppose instead to have a scalable OFDM modulator/demodulator, that means the (I)FFT processing block is implemented in such a way that it can perform different lengths FFT at different speeds (FFT = fast Fourier transform, IFFT = inverse fast Fourier transform). In other words, if it is able to compute an N-point FFT with a clock frequency  $f_{\text{CLK}}$  it is also able to perform an  $N/2^n$ -point FFT at  $f_{\text{CLK}}/2^n$  ( $n=1,2,\dots$ ). From the system point of view, this means that if not required by the rate constraint, the system can allocate a smaller potential bandwidth (e.g.  $B/4$ ) for the current transmission so that it can work at a lower speed (e.g.  $f_{\text{CLK}}/4$ ) (see Figure 4A). This implies a huge reduction in the required processing power because this processing power is mainly due to the clock frequency. As a general rule, if the total bit rate that the device is required to provide, is  $1/K$  with respect to the maximum, the clock frequency and the number of FFT/IFFT points will be reduced this factor. In this way power consumption is reduced by  $K^2 \cdot \log_2 N / \log_2 (N/K)$ .

Given such a scalable FFT, the problem exists to manage this system flexibility in order to optimize the transmission, aiming at minimizing the processing power required by the current channel condition and QoS constraints (Target\_Rate and Target BER).

The algorithm works this way:

I. Accept Inputs:

a. Target\_Rate: required information rate

5 b. Target\_BER: required Bit Error Rate

---

c. Channel condition  $H = \{|H_i|^2\}$ : set of the channel power transfer functions  
(index i refers to the  $i^{\text{th}}$  sub-carrier (sub-channel))

2. Compare Target\_Rate and Rate\_(N) for each available N (from 1 to  
10 max\_available\_N).  $\text{Rate}_N = C \cdot \log(M) \cdot N$ . It defines the maximum rate obtainable with  
a total number of sub-channels equal to N. Of course it refers to the highest code rate and  
constellation size available for the considered system.

3. Select and accept the values of N satisfying  $\text{Target\_Rate} \leq \text{Rate}_N$   
15

This permits to discard the values of N that do not respect the rate constraint.

4. Order these values in ascending order to get  $[N_{\min}, N_{\max}]$

20 Form the processing point of view  $N_{\min}$  would be always the optimum value,  
but, along with the process power, the transmission power has to be taken into account.  
Maybe that, with  $N_{\min}$  total sub-channels, high values C and M are necessary to get the  
Target\_Rate and the corresponding transmission power, required to achieve the Target\_BER,  
exceeds the maximum available. Of course, this depends also on the current channel  
25 condition experienced by the  $N_{\min}$  sub-channels. Suppose no (M,C) combination meets the  
transmission power constraint for the current channel condition. It means a higher number of  
total sub-channels is required with a new check procedure on transmission power. This “try  
and check” process needs to be iterated until the first solution is found. It must be noted that,  
in the “check” procedure, the position of the  $N_{\min}$  sub-channels. with respect to the total  
30 bandwidth allocated to the system, is also very important because different positions  
correspond to different sets of channel coefficient. Assuming to have the possibility to shift,  
after the IF the spectrum of the signal to be transmitted (there are  $\text{max\_available\_N} - (N_{\text{opt}} - 1)$   
possible positions), this degree of freedom must be taken into account in order to improve the  
power minimization procedure.

5. Assume  $N_{\text{opt}} = N_{\text{min}}$

- (a) Select the best window position among the possible ones (max\_available  $N - (N_{\text{opt}} - 1)$ ).

This could be efficiently done before the transmission power minimization procedure, being minimization criterion known (e.g. suppose the minimization is based on the worst sub-channel) then the best window is the one having the highest value for the worst sub-channel.

- (b) Run the adopted TX power minimization algorithm on the selected window.

To be more explicit, TX power minimization algorithm here refers to one of the possible algorithms, based on the channel state information, aiming at the selection of the transmission parameters that guarantee the required QoS (bit rate and BER) with the minimum transmission power (see supervisor algorithm: transmission power minimization).

- (c) Check if the transmission power constraint is satisfied. If so jump to step 6, if not go to 5(d)

- (d) Check if another value is available in the set  $[N_{\text{min}}, N_{\text{max}}]$ . If so choose the next (next\_N), set N to next\_N and jump to 5(a). If not set  $N_{\text{opt}} = 0$ . This will be interpreted as a flag meaning that no "optimum" solution for N exists.

6. Provide Outputs:

- a.  $N_{\text{opt}}$   
b. Minimum TX power parameters

This algorithm can be applied in every OFDM-based system in which a scalable IFFT/FFT is adopted. The maximum benefit deriving from this power saving feature is of paramount importance in mobile/portable wireless systems for which battery life always is an issue.

**Supervisor Algorithm: transmission power minimization**

The minimum transmission power supervisor algorithm performs, in the supervisor unit, the real-time adaptive system optimization. It is meant to optimize the transmission through frequency selective channels in coded OFDM (orthogonal frequency

5 division multiplex) based systems. Given the current channel condition, the algorithm determines the optimum combination of the transmission parameters to fit the QoS requirements coming from the MAC layer with the minimum transmission power. The combination has to be considered 'optimum' with reference to the low computational complexity required by the algorithm when compared to traditional solutions.

10 The supervisor performs its optimization at PHY level and this allows a true real-time optimization. The supervisor supplies also the  $MAC_{out}$  information to the upper layer allowing MAC to perform its own optimization process.

The processing unit interface is the interface between the processing unit block, e.g. the -supervisor, the other PHY layer blocks and the MAC layer. This interface is meant for the minimization of the transmitted power given, as input parameters, the current

15 channel conditions and QoS from MAC. The processing unit interface provides two different outputs, one towards the other PHY blocks and the other towards the MAC layer. The output interface towards the other PHY blocks is an appropriate set of transmission parameters sufficient to specify any flexible transmission system (i.e. block/convolutional/turbo coded

20 single-/multi- carrier modulated system with/without bit and/or power loading). The output interface towards the MAC layer specifies the actual performance achieved and gives feedback information about the maximum available performance of the PHY layer with the current channel conditions. Such inputs and outputs are shown in Figure 2 and more in detail in Figure 3.

25 From MAC:

QoS requirements at PHY layer:

Target\_Rate: required information rate

30 Target\_BER: required Bit Error Rate

Max\_Delay: max tolerable delay

MAC feedback request type:

Service\_mode [0/1]: one bit information to specify if MAC QoS requirements refers to a Rate guaranteed service or to a BER guaranteed service. In case the current channel conditions prevent to satisfy requirements even with the maximum available power, this information determines whether with this power the Target\_Rate will be guaranteed with the minimum available BER or the Target\_BER will be guaranteed with the maximum available Rate.

Feedback\_mode [0/1]: one bit information to specify if MAC is interested to have a feedback information on the "current" maximum available rate or the minimum available BER (see OUTPUTS) in order to define its next QoS request.

From PHY:

$H = \{|H_i|^2\}$ : set of the channel power transfer functions (index  $i$  refers to the  $i^{\text{th}}$  sub-carrier (sub-channel), for single-carrier systems no index is needed)

Output to PHY:

C: Code rate

20 B: Block length

N: number of decoding iterations (e.g.  $N=0$  means that the channel coding is not a Turbo coding scheme, different values in the pre-defined available set specify the number of required decoding iterations)

$M = \{M_i\}$ : set of codes to specify the generally different constellations adopted for the different sub-channels (e.g.  $M_i=0$  means that the  $i^{\text{th}}$  sub-channel is OFF, different values specify constellation types in the pre-defined available set)

$P = \{P_i\}$ : set of the generally different transmission powers adopted for the different sub-channels (e.g.  $P_i=0$  means that the  $i^{\text{th}}$  sub-channel is OFF)

30 Output to MAC:

Actual\_Rate: rate actually determined for the current transmission. It is expected to be equal to or greater than the Target\_Rate, but it can be also smaller in case the current channel conditions prevent to satisfy requirements even with the maximum available

power. In this case, if the service is a BER guaranteed one, this value is equal to the maximum available Rate.

Actual\_BER: BER actually determined for the current transmission. It is expected to be equal to or smaller than the Target\_BER, but it can be also greater in case the current channel conditions prevent to satisfy requirements even with the maximum available power. In this case, if the service is a Rate-guaranteed one, this value is equal to the minimum available BER.

MAC\_return: Depending on the Feedback\_mode request from MAC, the Max\_available\_Rate or the Min\_available\_BER is provided after the optimization processing.

Max\_available\_Rate: maximum available rate for the current channel condition as far as BER and tolerable delay requirements are respected. This rate is obtained if the total power equals to the maximum defined by the system specifications.

Min\_available\_BER: minimum available BER for the current channel condition as far as rate and tolerable delay requirements are respected. This BER is obtained if total power equals the maximum defined by the system specifications.

Within this framework of high-performance, flexible, QoS-aware, low-power digital transceivers, a reduced-complexity algorithm for fast, joint optimization of the transmission parameters in OFDM indoor wireless systems is based on the sub-carrier switching concept, is handled by the supervisor unit, that is the basic processing and control unit of any adaptive and re-configurable system, meant to perform, real-time, a predefined system optimization. The proposed algorithm dynamically determines the modulation and channel coding parameters for an OFDM-based system operating in frequency selective environments. Based on the channel state information, the algorithm selects the transmission parameters that guarantee the required QoS (bit rate and BER) with the minimum transmission power.

The core of the supervisor algorithm calculates the optimum constellation size, channel code rate, number and position of active sub-carriers (sub-channels) and transmit power for an OFDM based transmission through frequency selective channels. Optimum here means that the parameters chosen by the supervisor algorithm guarantee, for the current channel condition, the bit rate and the BER requested by the MAC sub-layer with the "minimum" transmit power. The power has to be considered the "minimum" obtainable with respect to the low complexity of the algorithm. The supervisor algorithm makes use of the



sub-channel switching (i.e. don't use high attenuated sub-channels if not strictly necessary to get the requested rate) and this is the reason why also the current number and position of ON sub-channels are part of the output information.

If the "minimum" power computed is greater than the maximum available power in the system, this maximum value is assumed to be the current "minimum" power and the algorithm is able to provide also one out of two possible sub-optimum solutions, depending on the type of service. In this case the supervisor algorithm provides either the maximum available bit rate for the required BER along with the corresponding set of parameters or the value of the minimum BER for the required bit rate along with the corresponding parameters. The first solution is intended for BER sensitive services (file transfer) while the second is suitable for Rate sensitive services (real-time voice/video).

The following assumptions are made:

1. The OFDM based transmission can be considered equivalent to N parallel and independent single-carrier transmissions
2. Every sub-band can be modeled as an AWGN channel with a flat channel response defined by a complex coefficient  $H$
3. The mean path loss and the channel power gain  $\alpha = |H|^2$  for every sub-channel, experienced at the receiver, are known at the transmitter
4. The transmit power, as well as the single-carrier constellation, are the same for every ON sub-channel
5. Code rate is the only adjustable parameter of the coding scheme
6. The coding gain in AWGN channels for each available constellation and code rate is known

The supervisor algorithm receives input data from the MAC sub-layer (the required BER and bit rate) and from the physical layer (the channel state information, i.e. the channel power gains, one per sub-channel). Moreover it can access static data from an internal LUT (Look-Up Table), such as the code gains for every couple constellation/code rate M/C in AWGN channel. Feedback mode input simply specifies whether the MAC, after the optimization procedure, is interested to receive back the information (called MAC\_return) about the current maximum available rate or the minimum available BER. Instead, the Service mode flag signals to the SV the type of service: one is for a guaranteed BER service, zero is for a guaranteed bit rate service. The output of the processing are the "optimum" couple M/C, the number and position of required sub-channels and the transmit power necessary to achieve the BER and bit rate requested by the MAC sub-layer. The transmit

power is the “minimum” one required to obtain the target QoS with a low complexity optimization algorithm. The supervisor algorithm also returns to the MAC sub-layer the actual bit rate and BER achieved, which should be always equal to or better than the required ones. In case the channel conditions prevent from achieving the required QoS, the supervisor algorithm sets up all the parameters of the current transmission aiming at the ~~Maximum Available Rate or at the Minimum Available BER, for guaranteed BER services or~~ guaranteed bit rate services respectively (Service\_mode specifies service type). In every case the algorithm also provides MAC with a feedback information about the maximum performance obtainable with the current channel condition: the Maximum available rate or the Minimum available BER. MAC specifies which value it is interested in by means of the Feedback\_mode flag. Feedback information can support MAC in determining the next QoS request.

#### Description of Detailed Algorithm

As stated above, the supervisor algorithm is able to solve the problem to find the “minimum” power solution:

(I) Find the M/C couple, the number and the position of the ON sub-channels required to fit the Target\_Rate and the Target\_BER requirements with the minimum power, given the current channel condition.

In case the channel conditions prevent from achieving the required QoS, even with the maximum available power, the supervisor algorithm sets up all the parameters of the current transmission aiming at the maximum available rate or at the minimum available BER, for guaranteed BER services or guaranteed bit rate services respectively (Service\_mode specifies service type). So it is able to solve also the following problems:

(Ia) Find the M/C couple, the number and the position of the ON sub-channels required to get the Maximum Rate compatible with the Target\_BER requirement, given the current channel condition and the maximum power allowed by the system specifications.

(Ib) Find the M/C couple, the number and the position of the ON sub-channels required to get the Minimum BER compatible with the Target\_Rate requirement, given the current channel condition and the maximum power allowed by the system specifications.

**Minimum transmission power for a target Rate and a target BER**

The input data from the MAC layer are: Target\_BER and Target\_Rate  $R$ . It should be noted that the very same algorithm can be adapted to find the minimum power required to satisfy the Target\_BER by turning off a pre-set number of sub-channels (e.g. 8%): just consider  $(1-\alpha)N$  instead of  $N$  in step 1 ( $\alpha$  is the fraction of OFF sub-channels) and skip step 3a ( $N^{(k,i)} = (1-\alpha)N$ ).

1. Calculate the maximum bit rate achievable by every couple M/C, identified by modulation  $k$  and code-rate  $i$ , with all sub-channels turned on:

$$R_{\max}^{(k,i)} = N \cdot R_n^{(k,i)}, \quad R_n^{(k,i)} = nbit_k C^i \quad (1)$$

where  $N$  is the total number of sub-channels,  $R_n^{(k,i)}$  is the pre-coded bit rate carried by the  $n$ th sub-channel by making use of modulation  $k$  and code-rate  $i$ ,  $C^i$  is the code-rate,  $nbit_k$  is the number of bits per modulation symbol. Note that this calculation can be performed off-line at initialization time.

2. Eliminate the couples M/C for which the maximum achievable bit rate is less than the requested one:  $R_{\max}^{(k,i)} < R$ .

3. For every couple useful M/C:

a. calculate the minimum number of sub-channels required to achieve the bit rate  $B$ :

$$N^{(k,i)} = \left\lceil \frac{R}{R_n^{(k,i)}} \right\rceil \quad (2)$$

where  $\lceil \cdot \rceil$  denotes the round up to the next integer. It should be noted that, in real implementations, the number of sub-channels is calculated so as to place an integer number of information bits per OFDM symbol. The way eq. (2) is rounded up, however, has no consequence for the remaining steps of the algorithm.

2. Derive, from simulation-based curves, the SNR necessary to obtain the required BER in the AWGN case (\*). Let  $SNR_{sub-channel}^{(k,i)}$  be the SNR required, for a single sub-channel, to operate @BER when using modulation  $k$  and channel coding  $i$ , assuming an AWGN channel:

5

---


$$SNR_{SC}^{(k,i)} = SNR_{SC}^k - G_c^i \quad (3)$$

where  $SNR_{sub-channel}^k$  is the uncoded SNR required by modulation  $k$  and  $G_c^i$  is the coding gain  $i$  (dB). Then, using  $N^{(k,i)}$  sub-channels, the received power will be:

10

$$P_{r,AWGN}^{(k,i)} = P_n snr_{SC}^{(k,i)} N^{(k,i)}, \quad (\text{not dB!}) \quad (4)$$

$P_n$  is the white noise power in the  $n$ th sub-channel band, and  $snr_{sub-channel}^{(k,i)}$  the signal-to-noise ratio for modulation  $k$  and code  $i$ .

15

(\*) This is the best way to derive the relation between BER and SNR for the single carrier coded modulation: no complex analytical relations, when obtainable, have to be worked out. It is worth to be underlined that the real channel is not supposed to be AWGN. This step is just a starting point for the algorithm, in which the real channel is considered in step 3c.

20

c. Let  $\vec{A} = \{a_1, a_2, \dots, a_N\}$  be the vector of the channel power gains for all  $N$  sub-channels. Let us assume, without loss of generality, that  $\vec{A}$  has been ordered in descending order and consider the leading  $N^{(k,i)}$  components:

$$25 \quad \vec{A}^{(k,i)} = \{a_1, a_2, \dots, a_{N^{(k,i)}}\} \quad (5)$$

Then  $a_{N^{(k,i)}}$  is the lower gain among the  $N^{(k,i)}$  necessary sub-channels: if the SNR on this sub-channel is greater than or equal to the required  $SNR^{(k,i)}$  (for modulation  $k$  and code-rate  $i$ ), then the very same condition will obviously hold for all the  $N^{(k,i)}$  sub-channels. The signal power at the receiver must be such that the above condition applies for the worst sub-channel, i.e. the received signal power calculated in step 3 must be scaled by the factor  $1/a_{N^{(k,i)}}$  :

30

$$P_r^{(k,l)} = (1 / a_{N^{(k,l)}}) \cdot P_{r,AWGN}^{(k,l)} \quad (6)$$

d. Calculate the total received power for all  $N^{(k,l)}$  sub-channels:

$$5 \quad P_{r,tot}^{(k,l)} = P_r^{(k,l)} \cdot N^{(k,l)} \quad (7)$$

4. The “optimum” couple M/C  $((M,C)_{\min\_pow})$  is the one which minimizes  $P_r^{(k,l)}$  (\*\*):

$$10 \quad P_{r,\min\_pow} = \min_{(k,l)} \{P_{r,tot}^{(k,l)}\} \quad (8)$$

If the minimum receive power (8) is below the sensitivity threshold  $T_r$  of the receiver, then the additional delta of power

$$15 \quad \Delta P = T_r - P_{r,\min\_pow} \quad (9)$$

is considered for the optimum couple, i.e. the receive power is set equal to the sensitivity threshold:

$$20 \quad P_{r,\min\_pow} = T_r \quad (10)$$

(\*\*) This is just an upper bound for the minimum required power but, to our knowledge, there is no way to derive the real BER of the whole coded OFDM symbol from the different BER of the various sub-channels. Even if there was such a relation it would be probably too complex to be implemented. A System design based on the above introduced upper bound can be considered in every case a good trade-off between complexity and performance.

5. The couple  $(M,C)_{\min\_pow}$  can achieve the actual rate  $R_{\min\_pow} = N_{\min\_pow} \cdot nbit_k \cdot C^d$  and the BER requested by the MAC sub-layer by using  $N_{\min\_pow}$  sub-channels and with the minimum possible transmit power, given by:

$$P_{t,min\_pow} = P_{r,min\_pow} + A \quad (dB) \quad (11)$$

where  $A$  is the mean path loss in  $dB$ . If  $P_{t,min\_pow}$  is greater than the maximum transmit power  $P_{t,MAX}$  of the system, then the supervisor algorithm returns the couple M/C yielding, @ $P_{t,MAX}$ , either the maximum available bit rate at given BER, or the minimum BER at given bit rate, depending on Service mode specification. In any case the supervisor algorithm supplies the MAC\_return value (maximum available rate  $R_{max}$  or minimum available BER  $BER_{min}$ ) and all the optimum outputs of the current transmission (Actual\_Rate, Actual\_BER, (M,C)<sub>opt</sub>,  $N_{opt}$  and  $P_{opt}$ ) to the MAC sub-layer.

#### Maximum Available Rate for a target BER and a given power

In this case, the starting information is the maximum transmit power and the Target\_BER. This function is called either if service mode is set to 1 (if  $P_{t,min\_pow} > P_{t,MAX}$ ) or if feedback mode is set to 1.

1. Calculate the maximum received power:

$$P_{r,max} = P_{t,max} - A \quad (dB) \quad (12)$$

where  $A$  is the mean path loss.

2. Let  $\vec{A} = [a_1, a_2, \dots, a_N]$  be the vector of the channel power gains for all  $N$  sub-channels, in descending order, and let  $\vec{P} = [p_j] = [P_{r,Max} / 1, P_{r,Max} / 2, \dots, P_{r,Max} / j, \dots, P_{r,Max} / N]$  be the vector of received power per sub-channel, assuming  $j$  sub-channels turned on. Then it is straightforward to calculate the minimum SNR on the weakest sub-channel, for every number  $j$  of sub-channels considered and store the result into a vector:

$$\overline{SNR} = \frac{1}{P_n} [a_1 p_1, a_2 p_2, \dots, a_N p_N] \quad (13)$$

- 30 Note that the  $j$ -th element  $\frac{a_j P_{r,Max}}{j P_n}$  is simply the SNR on the worst sub-channel among the  $j$  sub-channels considered. Note also that the  $SNR$  vector is ordered in descending order.

3. For every couple M/C:

a. calculate the number of sub-channels having an SNR above the threshold

5 yielding the BER requested by the MAC sub-layer:

$$N^{(k,i)} = \min_j \{ \overrightarrow{SNR}_j \geq SNR^{(k,i)} \} \quad (14)$$

where the function  $\min_j \{cond\}$  returns the minimum index  $j$  for which the condition  $cond$

10 holds.

4. Calculate the bit rate achievable using  $N^{(k,i)}$  sub-channels:

$$R_{MAX}^{(k,i)} = N^{(k,i)} R_n^{(k,i)} \quad (15)$$

15

5. Find the M/C (called  $(M,C)_{max}$ ) yielding the maximum bit rate:

$$R_{MAX} = \max_{(k,i)} \{ R_{MAX}^{(k,i)} \} \quad (16)$$

20 and  $N_{max}$  is the  $N^{(k,i)}$  sub-channels for  $(M,C)_{max}$ .

### Minimum Available BER for a target Rate and a given power

The starting information is the maximum transmit power and the Target\_Rate.

This function is called either if service mode is zero (if  $P_{t,min\_pow} > P_{t,MAX}$ ) or feedback mode  
25 is zero.

1. Calculate the maximum receive power:

$$P_{r,max} = P_{t,max} - A \quad (dB) \quad (17)$$

30

where  $A$  is the mean path loss.

2. For every M/C:

a. calculate the number of sub-channels used to achieve the bit rate  $R$ :

5

---


$$N^{(k,i)} = \frac{R}{R_n^{(k,i)}} \quad (18)$$

b. the SNR (signal-to-noise-ratio) on the worst sub-channel is:

$$10 \quad SNR_{MIN}^{(k,i)} = a_{N^{(k,i)}} \frac{P_{r,MAX}}{P_n N^{(k,i)}} \quad (19)$$

c. The BER corresponding to the worst sub-channel can be calculated from the BER-SNR curve for modulation  $k$  and code-rate  $i$ .

15 3. Find the M/C (called  $(M,C)_{min}$ ) yielding the minimum value:

$$BER_{MIN} = \min_{(k,i)} \{BER^{(k,i)}\} \quad (20)$$

and  $N_{min}$  is the  $N^{(k,i)}$  sub-channels for  $(M,C)_{min}$ .

20 Several simulations have been performed in the WIND-FLEX scenario. The WIND-FLEX system architecture is based on Turbo channel coding, OFDM modulation scheme and provided with a supervisor unit for real-time system optimization.

25 Figure 10A, 10B and 10C show performance results obtained by applying the method using the supervisor algorithm, compared to the performances without supervisor algorithm implemented. Figure 10A, 10B and 10C show the mean RX power of a NLOS channel versus the available sub-carrier modulation schemes BPSK (binary phase shift keying), QPSK (quadrature phase shift keying), 16-QAM and 64-QAM. In Figure 10A, the transmission rate is 72Mbit/s and the @BER is 1e-5, in Figure 10B the transmission rate is 72Mbit/s and the @BER is 1e-6 and in Figure 10C the transmission rate is 108Mbit/s and the  
30 @BER is 1e-5. The available sub-carrier modulation schemes are adaptively chosen. The



total number of useful sub-carriers is 100 but a variable number of sub-carriers can be also adaptively switched-off (sub-channel switching).

The coding scheme is a parallel convolutional turbo code. The available code rates are 1/2, 2/3 and 3/4 and the block length is adaptive and dependent on the triplet: code  
5 rate, constellation size, and number of ON sub-carriers.

The 17 GHz channel model provided by the WIND-FLEX Consortium has been adopted. The channel exhibits a frequency-selective behavior, which translates into few deep fades in the 50MHz-wide spectral response.

The worst-case scenario, i.e. NLOS channel and maximum distance from the  
10 transmitter (5 meters), has been considered. For each simulation 10000 channel realizations have been used, that is: the supervisor algorithm was run 10000 times, and for every channel realization the “optimum” couple M/C, giving the required QoS with the minimum transmit power, was found. Note that the optimum couple - and the required power - is not always the same for different channel realizations. The bottom horizontal line is the minimum power  
15 line and, in the graphs, defines the minimum average received power required. It is obtained by selecting, for each channel realization, the received power of the optimum M/C couple and then averaging over the total number of channel realizations. The graphs also show the average power required by each couple M/C. Some couples are missing because they would require a power level higher than the maximum allowed by system specifications (10 dBm  
20 EIRP transmit power).

Note that when no supervisor algorithm is applied, the optimum couple M/C is always the same for every channel realization (e.g. 16 QAM with 3/4-rate convolutional turbo coding in Figure 10A, therefore the level of the minimum power line is defined by the average power required by this modulation/coding scheme. When the supervisor algorithm is  
25 applied, on the other hand, the optimum couple may change, therefore the minimum power line does not generally correspond to the power level required by a single couple (Figure 10B and Figure 10C). Note also the significant amount of power saved by using the supervisor algorithm, especially when high bit rates/low BERs are requested by the MAC layer.

A simple and effective algorithm that can be run by any adaptive, QoS-aware,  
30 OFDM receiver has been developed and proposed. The algorithm is based on the sub-carrier switching technique and is able to solve the problem of finding the modulation/coding scheme and the number and position of the ON sub-carriers required to fit the Target\_Rate and the Target\_BER requirements with the “minimum” power, given the current channel condition. The proposed solution can be considered a good trade-off between complexity and

performance with respect to the theoretical optimum given by the “water filling” solution. Moreover, this reduced-complexity algorithm is suitable for the real-time applications. The supervisor algorithm, as described in this paper, gives just an upper bound for the minimum required power. A way to derive the real BER of the whole coded OFDM symbol from the different BER of the various sub-channels is under investigation in the WIND-FLEX project framework.

---

To summarize a preferred embodiment, a method for minimizing processing and transmission power in a flexible and reciprocal OFDM wireless communication system including a MAC layer and a PHY layer, said PHY layer including a supervisor unit controlling real-time the performance of the PHY layer is disclosed. The method comprises feeding a first set of input data as to the QoS requirements at the PHY layer from the MAC layer to the supervisor unit comprising a Target\_Rate (required information rate), a Target\_BER (required Bit Error Rate) and a Max\_Delay (max tolerable delay); feeding a second set of input data including channel power transfer functions  $H = \{|H_i|^2\}$ : (index  $i$  refers to the  $i^{\text{th}}$  sub-carrier ) from PHY layer to the supervisor unit; processing the first and second set of input data for minimizing processing and transmission power in a wireless communication network system; and outputting  $N$ , modulation and coding parameters and transmission power parameters to the PHY layer. The coding parameters and transmission power parameters to the PHY layer include  $C$ : Code rate data;  $B$ : Block length data;  $n$ : data as to the number of decoding iterations;  $M = \{M_i\}$ : data as to a set of codes to specify the generally different constellations adopted for the different sub-channels (e.g.  $M_i=0$  means that the  $i^{\text{th}}$  sub-channel is OFF, different values specify constellation types in the pre-defined available set); and  $P = \{P_i\}$ : data as to a set of the generally different transmission powers adopted for the different sub-channels (e.g.  $P_i=0$  means that the  $i^{\text{th}}$  sub-channel is OFF).

The minimum transmission power supervisor algorithm described is meant to perform, in the supervisor unit, the adaptive system optimization. It is a link adaptation algorithm. New characteristics and advantages of the invention covered by this document have been set forth in the foregoing description. It will be understood, however, that this disclosure is, in many respects, only illustrative. Changes may be made in details, particularly in matters of shape, size, and arrangement of parts, without exceeding the scope of the invention. The scope of the invention is, of course, defined in the language in which the appended claims are expressed.

## CLAIMS:

13.09.2002

(93)

1. Method for minimizing transmission power in an OFDM wireless communication system including a MAC layer and a PHY layer, said PHY layer including a supervisor unit controlling performance of the PHY layer, wherein:
  - a) processing of first and second sets of input data for minimizing transmission power in a wireless communication network system comprises:
    - b) calculating the maximum bit rate achievable by every couple M/C, identified by modulation k and code-rate i, with all sub-channels turned on;
    - c) eliminating the couples M/C for which the maximum achievable bit rate is less than the requested one;
    - 10 d) for every couple useful M/C:
      - d1) calculate the minimum number of sub-channels required to achieve the bit rate B;
      - d2) derive, from simulation-based curves, the SNR necessary to obtain the required BER in the AWGN case and use it to derive the SNR required by the worst sub-
 15 channel;
      - e) calculate the total received power for all  $N^{(k,i)}$  sub-channels;
      - f) select and output an "optimum" couple M/C  $((M,C)_{\min\_pow})$  which minimizes  $P_r^{(k,i)}$ :
 
$$P_{r,\min\_pow} = \min_{(k,i)} \{P_{r,tot}^{(k,i)}\}$$
- 20 2. The method of claim 1, wherein, in case the starting information is the maximum transmit power and the Target\_BER, the processing of the first and second set of input data for minimizing transmission power in a wireless communication network system comprises:
  - a) calculate the maximum received power;
  - 25 b) calculate the minimum SNR on the weakest sub-channel, for every number j of sub-channels considered and store the result;
  - c) for every couple M/C, calculate the number of sub-channels having an SNR above the threshold yielding the BER requested by the MAC sub-layer;
  - d) calculate the bit rate achievable using  $N^{(k,i)}$  sub-channels;

- e) find the M/C (called  $(M,C)_{\max}$ ) yielding the maximum bit rate; and
- f) select and output an "optimum" couple M/C (called  $(M,C)_{\max}$ ).

3. The method of claim 1, wherein, in case the starting information is the

5 maximum transmit power and the Target\_Rate, the processing of the first and second set of  
~~input data for minimizing transmission power in a wireless communication network system~~  
 comprises:

- a) calculate the maximum receive power;
- b) for every M/C, calculate the number of sub-channels used to achieve the bit  
 10 rate Target\_Rate;
- c) select the SNR on the worst sub-channel;
- d) calculated from the BER-SNR curve the BER corresponding to the worst sub-channel for modulation  $k$  and code-rate  $i$ ;
- e) find the M/C (called  $(M,C)_{\min}$ ) yielding the minimum value; and
- 15 f) select and output an "optimum" couple M/C (called  $(M,C)_{\min}$ ).

4. Method for minimizing processing power in an OFDM wireless communication system including a MAC layer and a PHY layer, said PHY layer including a supervisor unit controlling performance of the PHY layer, wherein:

- 20 a) processing of first and second sets of input data comprises:
- b) comparing Target\_Rate and  $\text{Rate}_N(N) = C \cdot \log(M) \cdot N$  for each available  $N$  (from 1 to  $\text{max\_available\_N}$ );
- c) selecting and accepting the values of  $N$  satisfying  $\text{Target\_Rate} \leq \text{Rate}_N(N)$ ;
- d) ordering these values in ascending order to get  $[N_{\min}, N_{\max}]$
- 25 e) assuming  $N_{\text{opt}} = N_{\min}$ ; and
- f) providing  $N_{\text{opt}}$  and minimum TX power parameters as output.

5. The Method of claim 4, further comprising, after assuming  $N_{\text{opt}} = N_{\min}$ ,

- checking if the transmission power constraint is satisfied, if so provide  $N_{\text{opt}}$
- 30 and minimum TX power parameters as output, if not
- go on to check if another value is available in the set  $[N_{\min}, N_{\max}]$ , if so choose the next (next\_N), set  $N$  to next\_N and jump to selecting and accepting the values of  $N$  satisfying  $\text{Target\_Rate} \leq \text{Rate}_N(N)$ , if not
- set  $N_{\text{opt}} = 0$  and provide  $N_{\text{opt}}$  and minimum TX power parameters as output.

6. The method of claim 5, wherein the processing of the first and second set of input data for minimizing transmission power in a wireless communication network system comprises:

- 5           selecting the best window position among the possible ones:  
            (max\_available N-( N<sub>opt</sub> -1)); and  
            running the adopted TX power minimization algorithm on the selected window.

- 10   7. The method of claim 1 and/or 4, comprising  
      feeding a first set of input data as to the QoS requirements at the PHY layer from the MAC layer to the supervisor unit;  
      feeding a second set of input data including channel power transfer functions  $H = \{|H_i|^2\}$ : (index i refers to the i<sup>th</sup> sub-carrier ) from PHY layer to the supervisor unit;  
15       processing the first and second set of input data for minimizing processing and transmission power in a wireless communication system;  
      outputting N, modulation, coding parameters and transmission power parameters to the PHY layer.

- 20   8. The method of claim 7, wherein the feeding of the first set of input data as to the QoS requirements at the PHY layer from the MAC layer to the supervisor unit comprises feeding a Target\_Rate (required information rate), a Target\_BER (required Bit Error Rate) and, preferably, a Max\_Delay (max tolerable delay).

- 25   9. The method of claim 7, wherein the outputting of coding parameters and transmission power parameters to the PHY layer comprises:  
      N: IFFT/FFT length;  
      C: Code rate data;  
      B: Block length data;  
30       n: data as to the number of decoding iterations;  
      M = {M<sub>i</sub>}: data as to a set of codes to specify the generally different constellations adopted for the different sub-channels (e.g. M<sub>i</sub>=0 means that the i<sup>th</sup> sub-channel is OFF, different values specify constellation types in the pre-defined available set); and

$P = \{P_i\}$ : data as to a set of the generally different transmission powers adopted for the different sub-channels (e.g.  $P_i=0$  means that the  $i^{\text{th}}$  sub-channel is OFF).

10. The method of claim 7, comprising outputting actual QoS data to the MAC  
5 layer.

---

11. The method of claim 1, 4 or 10, wherein outputting actual QoS data to the MAC layer comprises outputting:

10 an Actual\_Rate (rate actually determined for the current transmission); and  
an Actual\_BER (BER actually determined for the current transmission).

12. The method of claim 10 or 11, wherein the MAC layer requests a feedback specifying a Feedback\_mode [0/1] (one bit information to specify if MAC is interested to have a feedback information on the "current" maximum available rate or the minimum  
15 available BER), and, furthermore, specifies a Service\_mode [0/1] (one bit information to specify if MAC QoS requirements refers to a Rate guaranteed service or to a BER guaranteed service).

13. The method of any of the claims 10 to 12, wherein the outputting actual QoS  
20 data to the MAC layer additionally comprises, depending on the Feedback\_mode request from MAC layer, outputting:  
a MAC\_return comprising a Max\_available\_Rate (maximum available rate for the current channel condition as far as BER and tolerable delay requirements are respected)  
or  
25 a Min\_available\_BER (minimum available BER for the current channel condition as far as rate and tolerable delay requirements are respected) is provided after the optimization processing.

14. The method of claim 1, 4 or 10, wherein the processing of the first and second  
30 set of input data for minimizing processing and transmission power in a wireless communication network system comprises finding N, the M/C couple and the ON sub-channels required to fit the Target\_Rate and the Target\_BER requirements with the minimum power, given the current channel condition.

15. The method of claim 14, wherein, in case the channel conditions prevent from achieving the required QoS even with the maximum available transmission power the supervisor algorithm, (depending on Service\_mode) finds the M/C couple, the number and the position of the ON sub-channels required to get

5 the Maximum Rate compatible with the Target\_BER requirement, given the current channel condition and the maximum power allowed by the system specifications, or the Minimum BER compatible with the Target\_Rate requirement, given the current channel condition and the maximum power allowed by the system specifications.

10 16. An OFDM wireless communication system including a MAC layer and a PHY layer, said PHY layer including a supervisor unit controlling performance of the PHY layer for minimizing processing and transmission power of the wireless communication system, wherein the supervisor unit is configured to perform any of the methods of claims 1 to 15.

15 17. A supervisor unit in an OFDM wireless communication network system including a MAC layer and a PHY layer, said supervisor unit being included in the PHY layer and controlling performance of the PHY layer for minimizing transmission power of the wireless communication system, the supervisor unit is configured to perform any of the methods of claims 1 to 15.

20 18. An interface unit in an OFDM wireless communication system including a MAC layer and a PHY layer, said PHY layer including a supervisor unit controlling performance of the PHY layer for minimizing transmission power of the wireless communication network system, said interface being located between the supervisor unit and  
25 the MAC layer, wherein said interface unit is configured to perform any of the methods of claims 1 to 15.

19. A computer readable medium containing a computer readable program for minimizing processing power in an OFDM wireless communication system including a  
30 MAC layer and a PHY layer, said PHY layer including a supervisor unit controlling performance of the PHY layer for minimizing processing and transmission power of the wireless communication system wherein the program when implemented in the supervisor and run in the supervisor unit causes the supervisor to perform the method of any of the claims 1 to 15.

## ABSTRACT:

13.09.2002

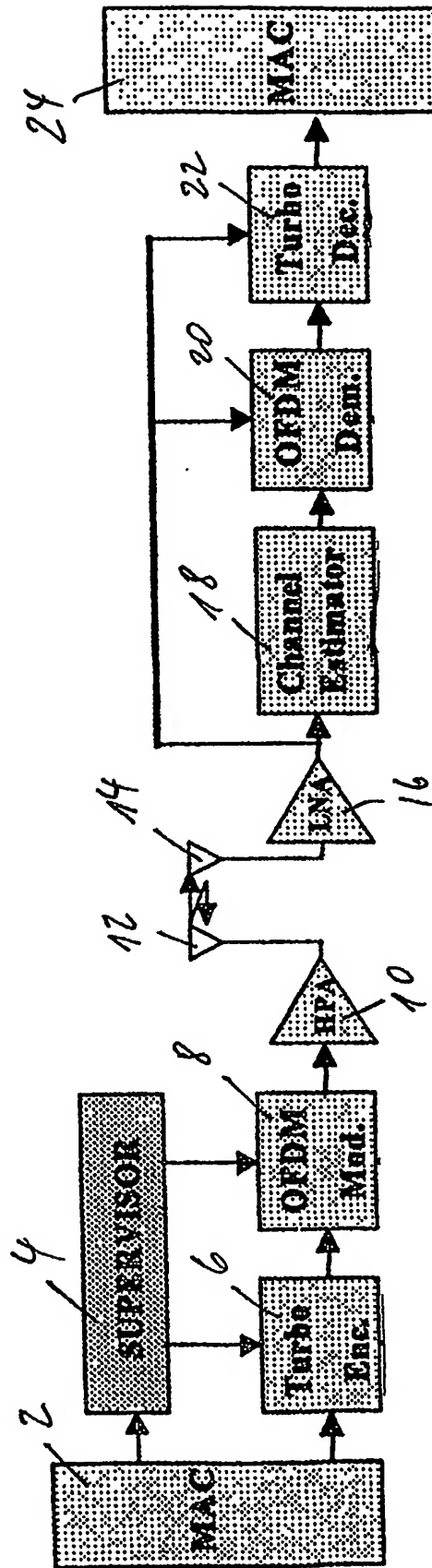
(93)

A method for minimizing processing and transmission power in a flexible and reciprocal OFDM wireless communication system including a MAC layer and a PHY layer, said PHY layer including a supervisor unit controlling real-time the performance of the PHY layer is disclosed. The method comprises feeding a first set of input data as to the QoS requirements at the PHY layer from the MAC layer to the supervisor unit comprising a Target\_Rate (required information rate), a Target\_BER (required Bit Error Rate) and a Max\_Delay (max tolerable delay); feeding a second set of input data including channel power transfer functions  $H = \{|H_i|^2\}$ : (index  $i$  refers to the  $i^{\text{th}}$  sub-carrier ) from PHY layer to the supervisor unit; processing the first and second set of input data for minimizing processing and transmission power in a wireless communication network system; and outputting  $N$ , modulation and coding parameters and transmission power parameters to the PHY layer. The coding parameters and transmission power parameters to the PHY layer include  $C$ : Code rate data;  $B$ : Block length data;  $n$ : data as to the number of decoding iterations;  $M = \{M_i\}$ : data as to a set of codes to specify the generally different constellations adopted for the different sub-channels (e.g.  $M_i=0$  means that the  $i^{\text{th}}$  sub-channel is OFF, different values specify constellation types in the pre-defined available set); and  $P = \{P_i\}$ : data as to a set of the generally different transmission powers adopted for the different sub-channels (e.g.  $P_i=0$  means that the  $i^{\text{th}}$  sub-channel is OFF). The method is performed in a wireless communication system, in particular in a supervisor unit .

Fig. 3



Fig: 1



1/10

EPO - DG 1

13.09.2002

93

Fig: 2

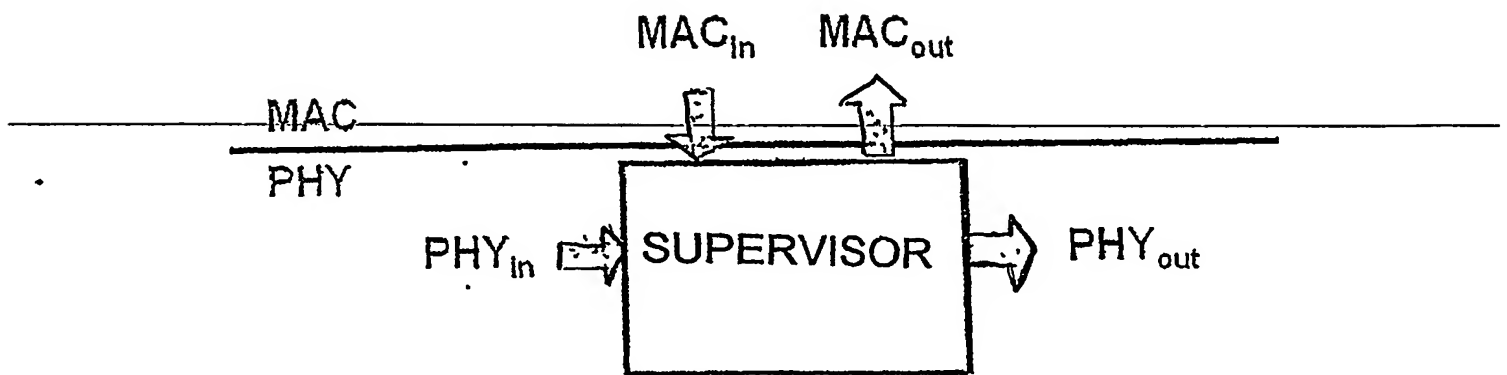
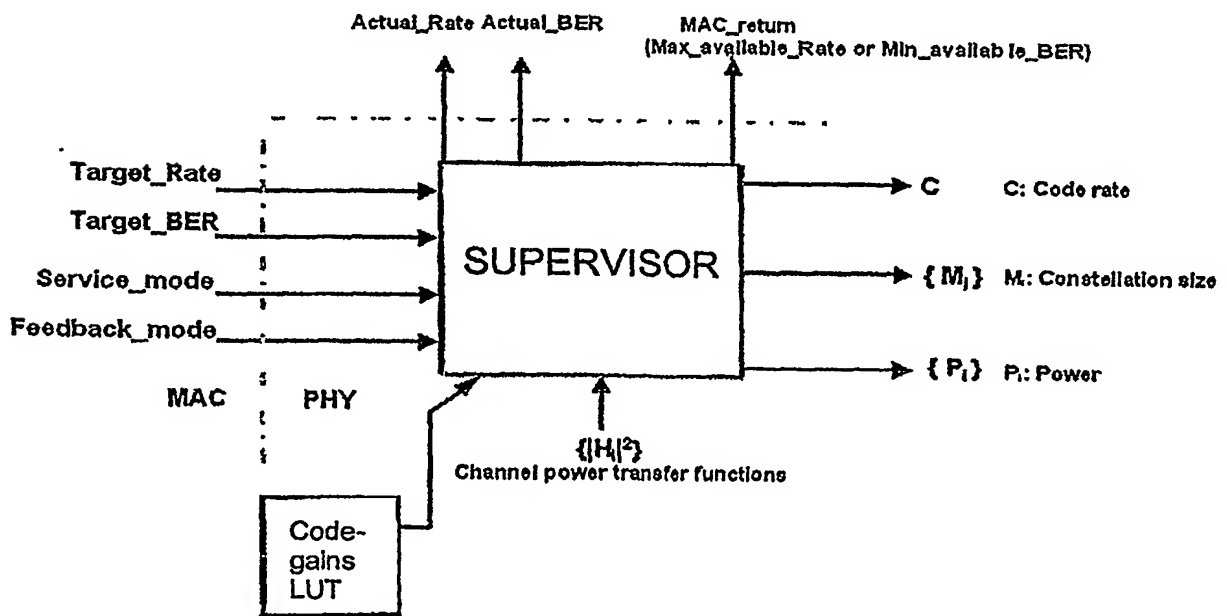


Fig: 3



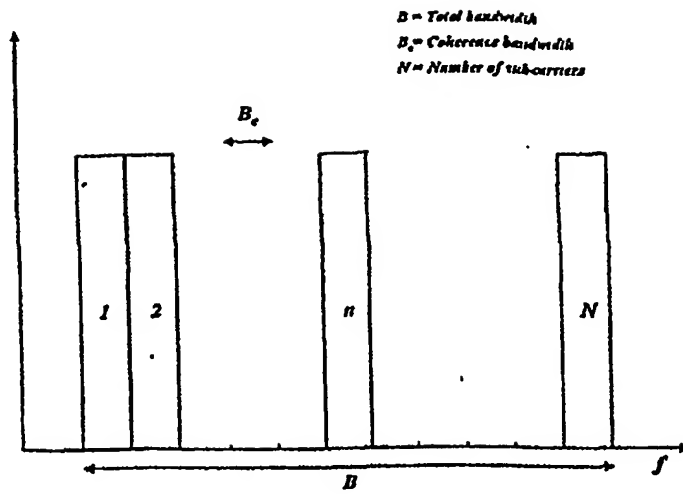


Fig: 4A

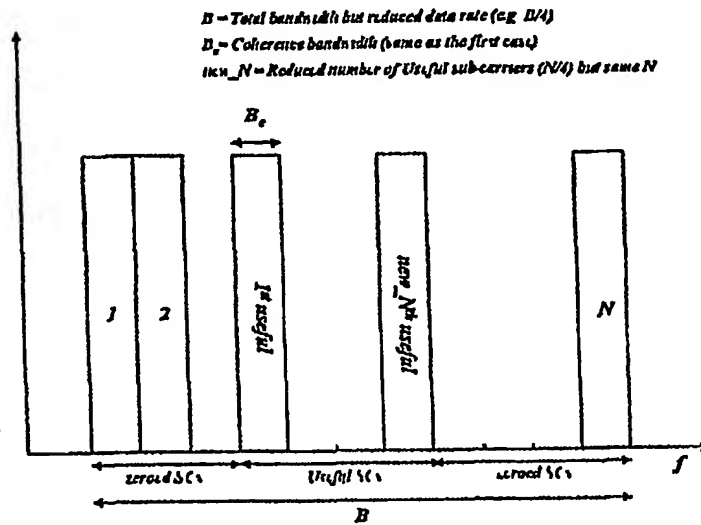


Fig: 4B

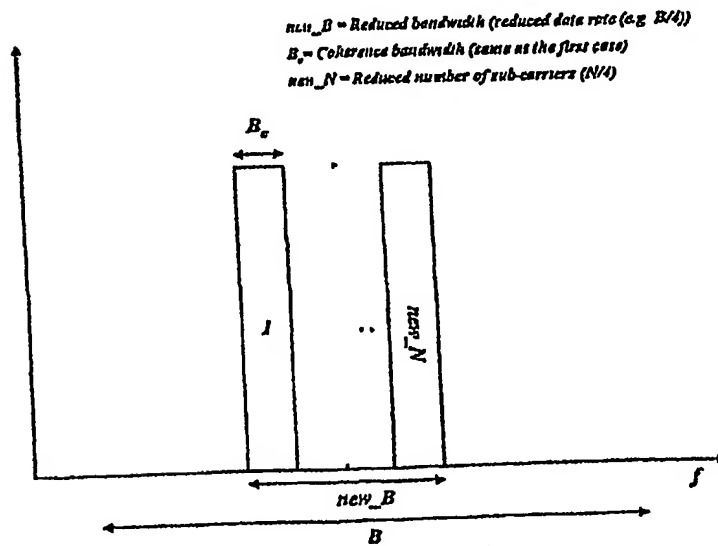


Fig: 4C

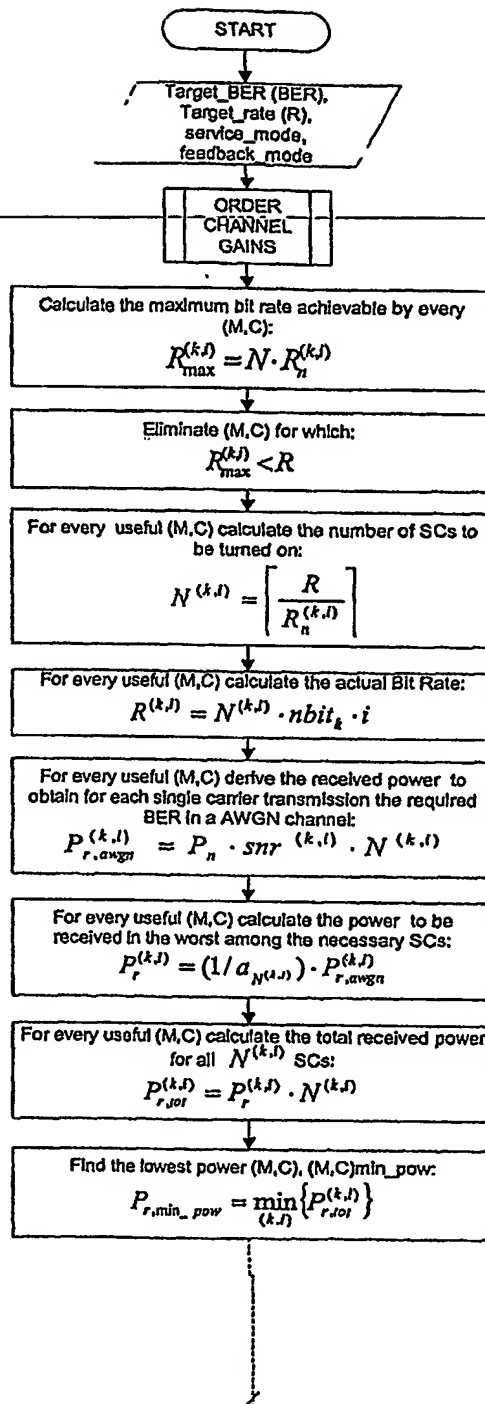


Fig: 5A

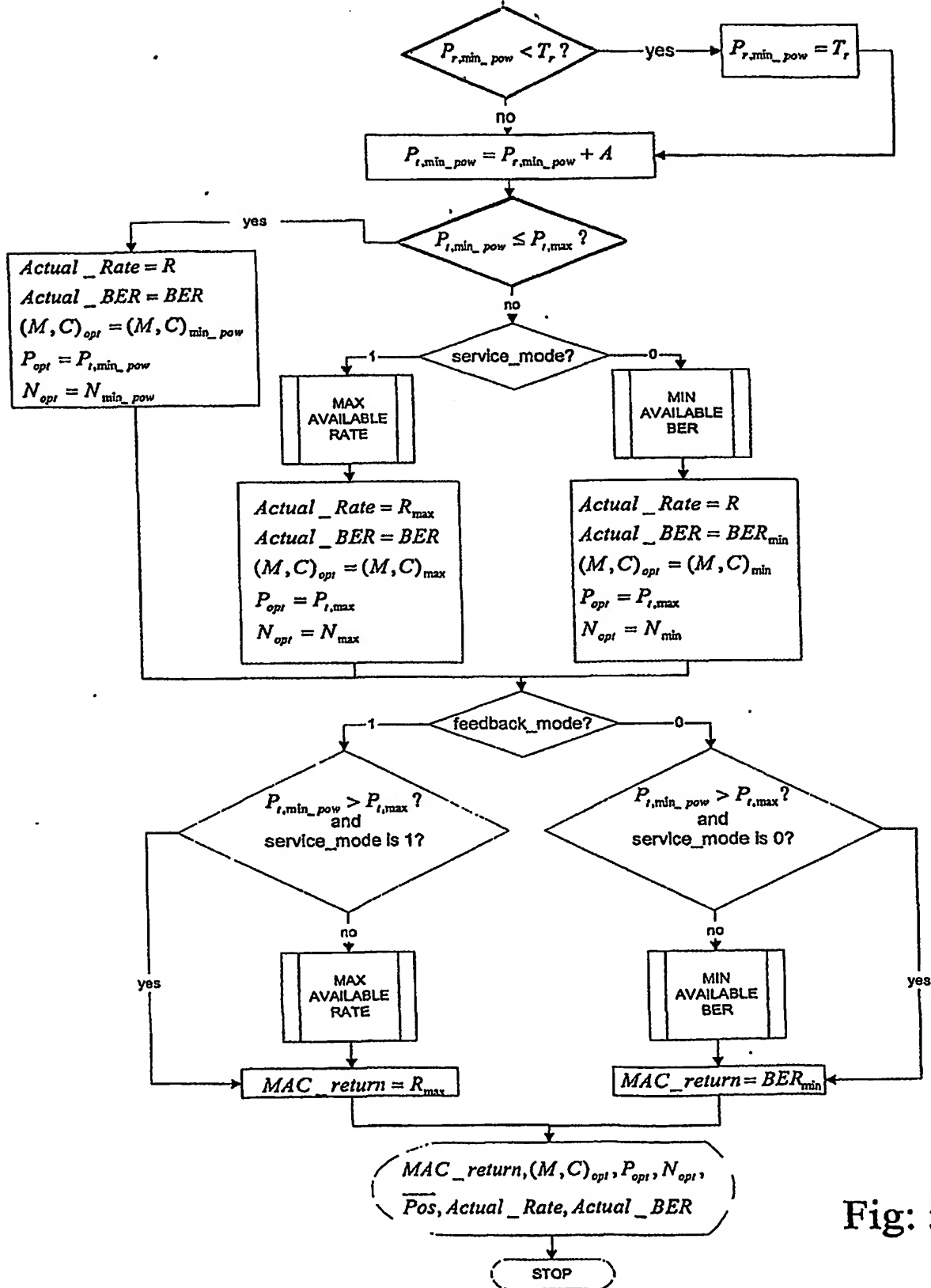


Fig. 5B

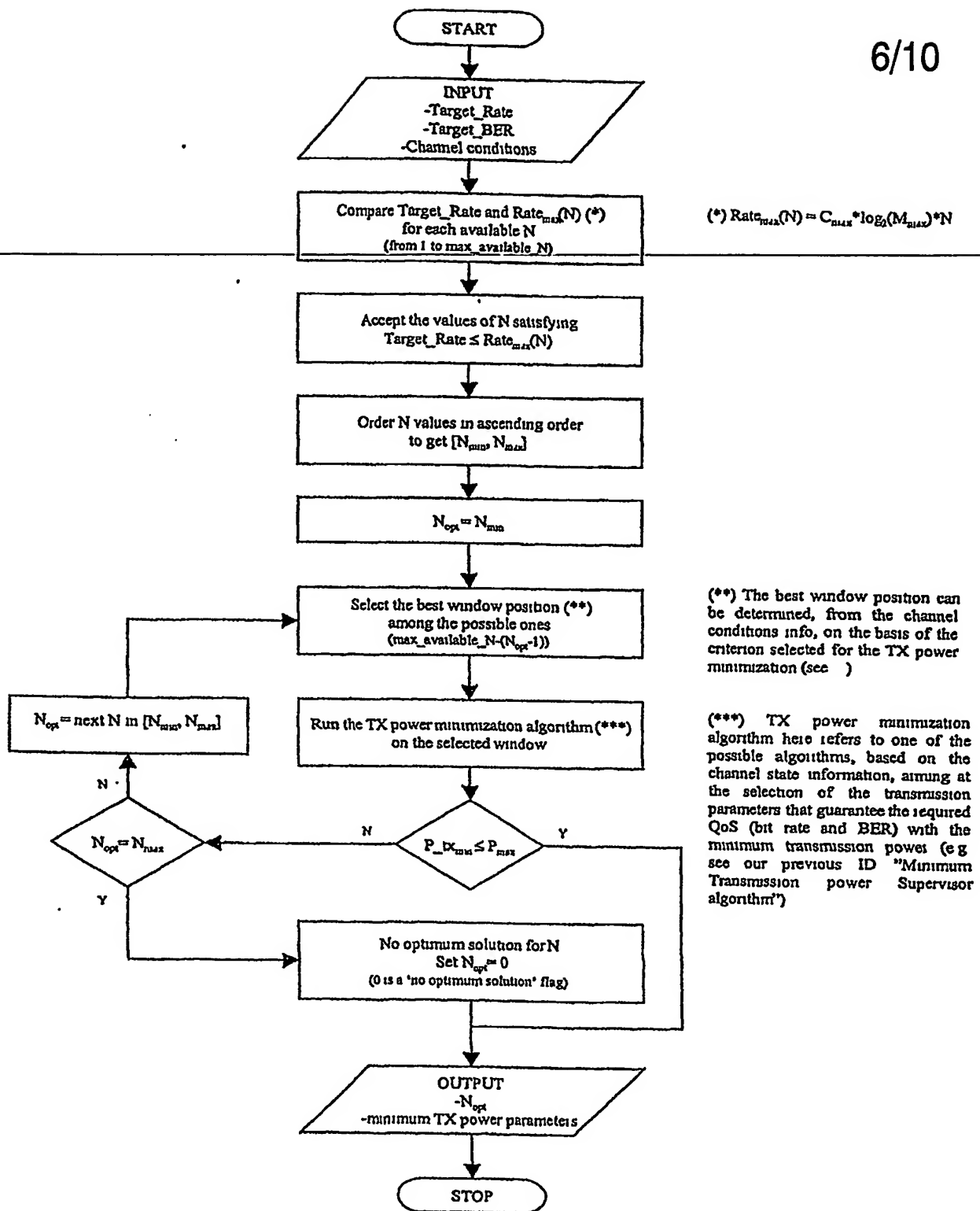


Fig: 6

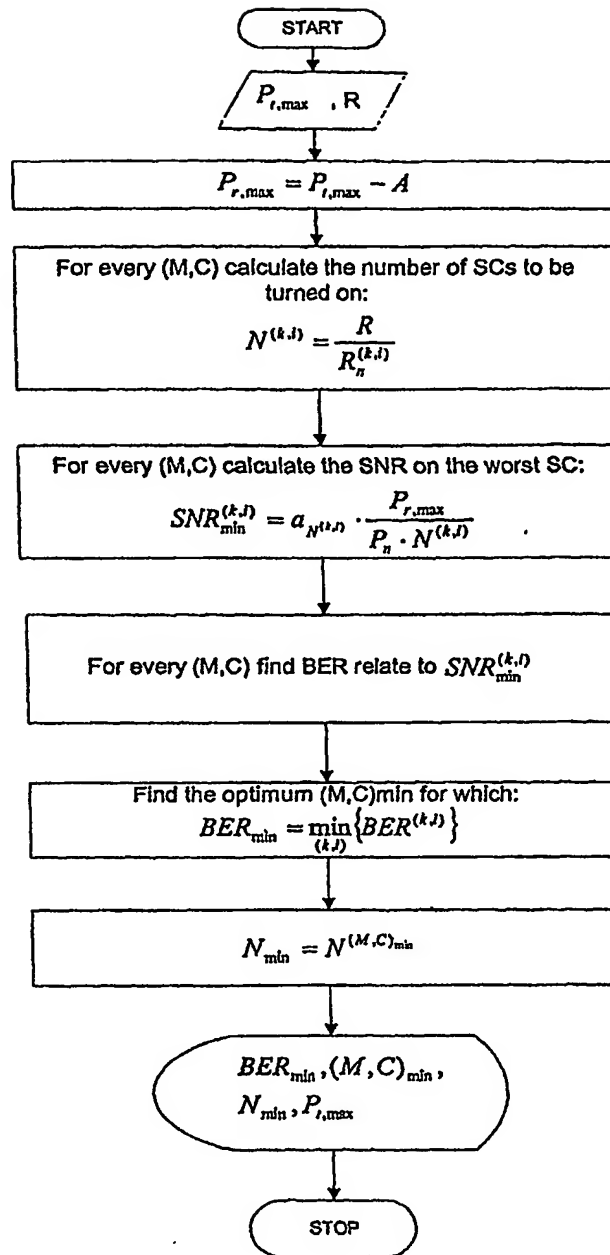


Fig: 7

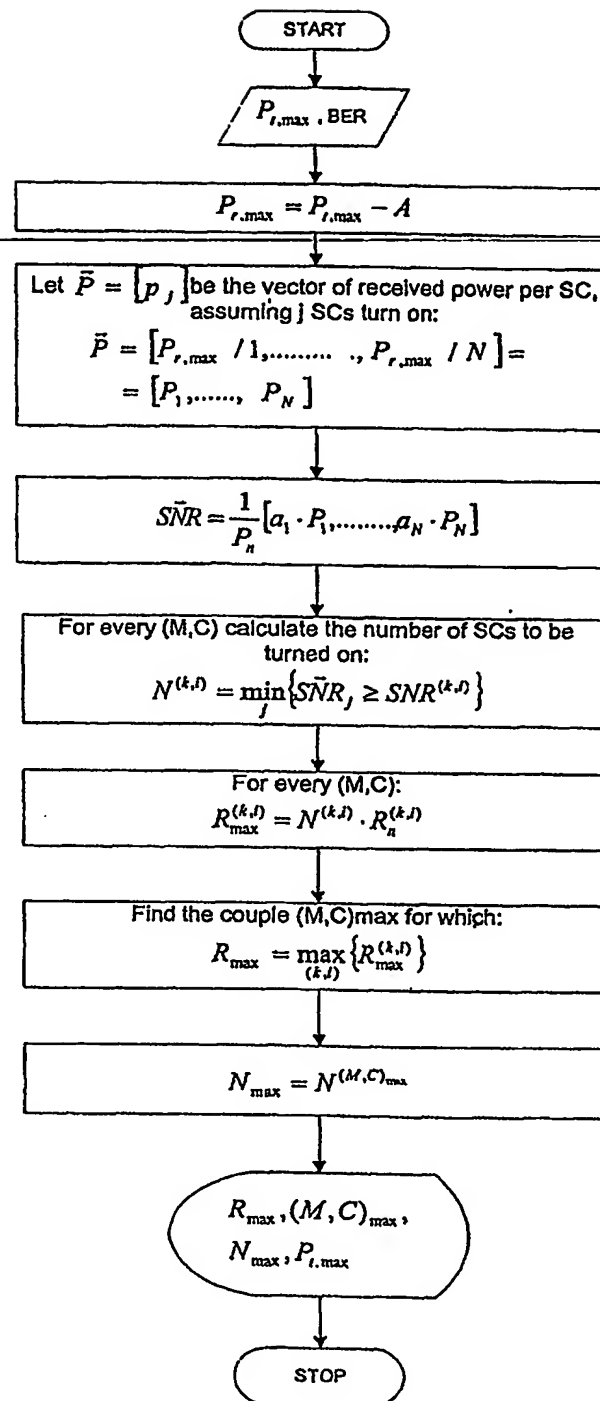


Fig: 8



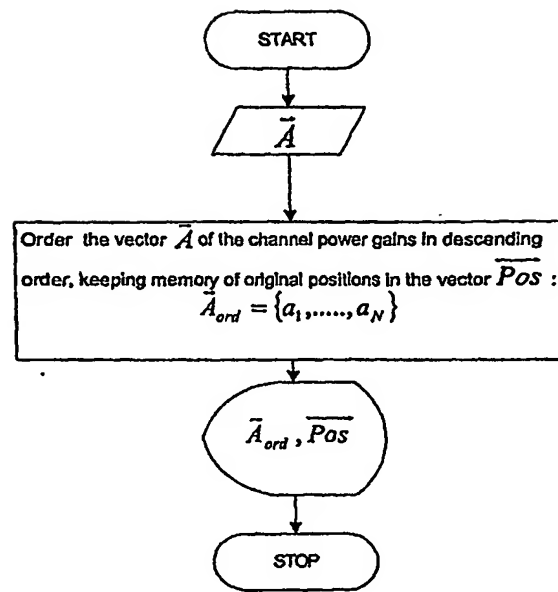


Fig: 9

10/10

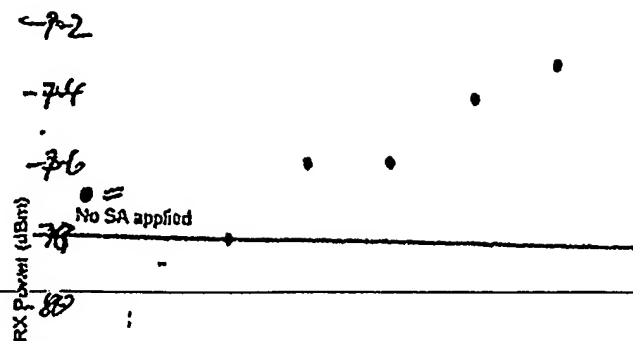


Fig: 10A

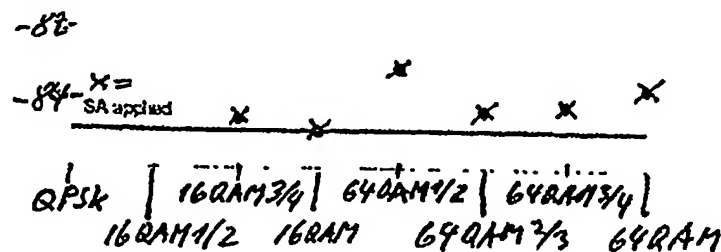


Fig: 10B

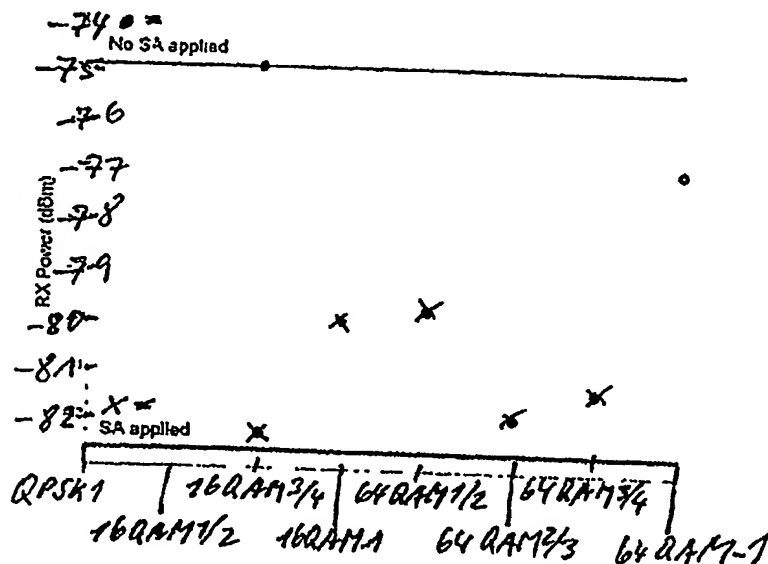
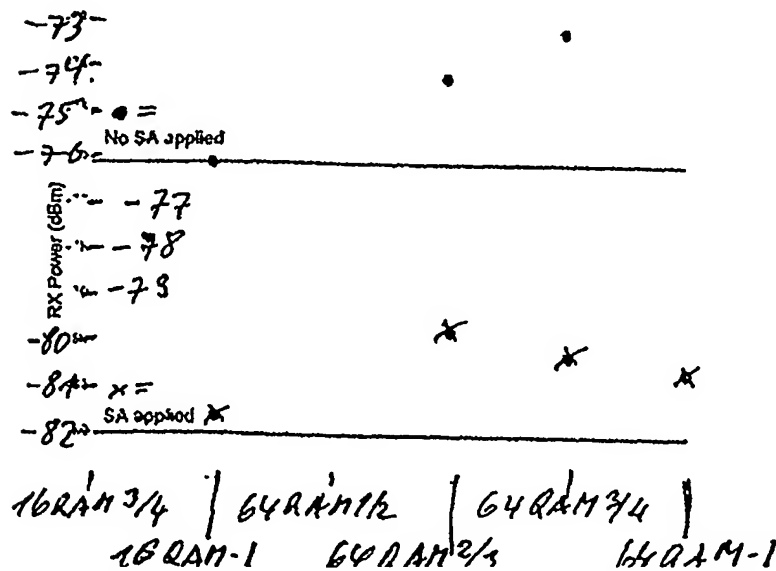


Fig: 10C



**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

**BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☒ **BLACK BORDERS**
- ☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☐ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKEWED/SLANTED IMAGES**
- ☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☐ **GRAY SCALE DOCUMENTS**
- ☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER:** \_\_\_\_\_

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**